# An Improved Method for Extraction of Historical Cartographic Features into GIS: A French Case Study


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**Abstract**

This paper presents an improved method for spatially accurate extraction of detailed features from historical cartographic sources for use in time series analysis in GIS. This method uses Adobe Photoshop to extract features from a series of maps in the southern Burgundy region of France, with dates ranging from 1759 to 2002. The method is defined and the benefits of this process are presented. Some preliminary results show the utility and improved spatial precision over previous methods.



***Key words**: Historical Maps, Digitizing,Georeferencing, France, GIS, Landscape change*


## 1 Introduction

Transferring data from historical maps into GIS databases has always been difficult, due to differing methods of map creation, manners of representation, inconsistencies of scale, and the outright spatial errors inherent in historical maps. Standard techniques of georeferencing key points on the landscape or rubber sheeting alone are not sufficient for tracking landscape change at the local level and at the scale of the individual land parcel. Jeremy Black, in his book *Maps and history: Constructing images of the past*, states:

> Many of the data problems for the fine-scale work on historical spatial patterns can be overcome by the development of accurate digitized maps and associated databases. [1]

This paper presents an improved method for more accurately transferring landscape features from historical maps into the modern GIS environment, using the transparency and layering features of the widely available Adobe Photoshop software. Once historical features have been accurately placed on a modern map of the area using this method, the placement is verified by archaeological field survey, and documented with GPS and Google Earth imagery before the data is finally incorporated into the GIS database.

Our research tracks land-use change over the past three centuries in the rural Commune of Uxeau in Southern Burgundy, France. The land in Uxeau has been continuously farmed by smallholders for millennia, maintaining a high productivity in all periods. By reconstructing historical landuse practices through both their social and physical aspects, we expect to uncover essential information on how people maintained the viability of this resilient landscape during periods of significant environmental, political, economic, social and cultural change. Many studies shaped by resiliency theory tend to focus on the collapse of socioecological systems.[2, 3] This research, based as

[1] Jeremy Black, *Maps and History: Constructing Images of the Past* (New Haven: Yale University Press, 1997).

[2] Joseph A. Tainter, *The Collapse of Complex Societies* (Cambridge: Cambridge University Press, 1988).

it is on a positive example of long-term successful adaptation, will be especially useful in refining theory and informing models of sustainability for the future.

Historical cadastral records for this period provide a history of landscape change tied to individual parcels and buildings from the year 1790 to the present. Periodic agricultural reports, from the early nineteenth century to date, add detail to the land-use information available from the cadastral records. Civil records of births, marriages & deaths are being used to reconstruct farm households, making it possible to connect households to the individual parcels through the tax records, thereby reconstructing the land holdings of farms.

The research adds to and is being analyzed as part of the extensive GIS data base of the area begun by Dr. Madry in the 1980s. The combined analysis of the demographic data with the land-use data in the GIS database will reveal each farm's land-use practices through time. The information from the cadastral records is supplemented by a series of detailed maps of the area dating to the years 1759, 1835, 1848, 1895, 1964, 1985 and 2002. The maps from 1835 and 1964 show the parcel outlines and numbers. In addition to the maps we have a series of scanned military aerial photos taken in 1945, and satellite imagery from various dates back to 1972. We present a preliminary example of water-related features extracted from these historical maps using our new method, that documents changes in water use and management over time.

## 2 Historical Map Digitization Context and Background

The analysis of historical cartographic data and the extraction of historical features within the GIS context has been of interest to a variety of disciplines including historical geography, history, anthropology, archaeology, and the general GIS community for the past decade.[4,5,6,7] There have been a variety of methods and approaches that have mirrored the current state of the technology and that have increased in complexity and sophistication. Author Madry has had a long term interest in the application of historical cartographic data into the GIS environment for archaeological and environmental applications. His work in this area includes projects such as the North Carolina archaeological predictive modeling and transportation planning,[8] Mountain Gorilla habitat analysis in Africa,[9,10] and our ongoing French project,[11,12] as well as publications on methodological approaches and issues.[13]

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[3] Charles L. Redman, *Human Impact on Ancient Environments* (Tucson: University of Arizona Press, 1999).

[4] Deryck Holdsworth, "Historical Geography: New Ways of Imaging and Seeing the Past," *Progress in Human Geography* 27, no. 4 (2003): 486-93.

[5] David Rumsey and Punt Edith M., *Cartographica Extraodinaire: The Historical Map Transformed* (Redlands, California: ESRI Press, 2004).

[6] Ann Knowles, editor, *Past Time, Past Place: GIS for History* (Redlands, California: ESRI Press, 2002).

[7] Ann Knowles, editor, *Placing History: How Maps, Spatial Data, and GIS Are Changing Historical Scholarship* (Redlands, California: ESRI Press, 2007).

[8] Scott Madry et al., "North Carolina Archaeological Predictive Modeling Project: Results of Task 1: Cabarrus, Chathamn, Forsyth, Granville, Guilford, Randolph, and Wake Counties," Prepared for the NCDOT and Federal Highway Administration by Environmental Services, Inc. Report on file at ESI and NCDOT., *ESI Report of Investigation* T.I.P. number E-4602, no. 416 (September 2007).

[9] H. Dieter. Steklis, et al., "A Geomatics Approach to Mountain Gorilla Behavior and Conservation," Conservation Keynote Session Paper, ESRI Users Meeting (San Diego, California, July 25-29 2005).

[10] Dieter Steklis, et al., "An Integrated Geomatics Research Program in Mountain Gorilla Behavior and Conservation," in *Conservation in the 21st Century: Gorillas as a Case Study*, ed. T. Stoinski, et al. (New York and London: Springer, 2008), 228-252.

[11] Scott Madry, "A GIS/Remote Sensing Case Study in Archaeology: Burgundy, France," in *Online Remote Sensing Tutorial, Section 15: Geographic Information Systems--the GIS Approach to Decision Making*, ed. Nicolas M. Short (NASA Goddard Space Flight Center, 2000).

## 3 Study Area

The study area for our long-term research program is the Arroux river valley in the Burgundy region of France. This specific study area for this phase of our long-term research comprises the commune of Uxeau, in eastern central France, in the Department of Saône-et-Loire in the southern Burgundy region. It ranges from 244-505 m in elevation and covers a land area of 32.75 $km^2$. It has a population, as of 2006, of 552 and consists of rolling hills and pastures above the Arroux river (see fig. 1).


**Figure 1.**
**The Study area in France**

## 4 French Project Background

This work is a part of a long-term research program that has been continuously underway in the Arroux river valley of Burgundy since 1974. Originally begun by Dr. Carole Crumley, this project has embodied the French concept of long duration studies (etudes du longue durée) as advocated by influential French historian Fernand Braudel (1902-1985). Our project has provided a context for researchers from a variety of disciplinary perspectives and backgrounds to work together in a ‘trans-disciplinary’ context to address long term questions of human settlement and land use over a period of over 2,000 years, from the Celtic Iron age to the present day.[14,15,16,17,18,19,20,21,22]

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[12]Scott Madry, "Des Gorilles Du Rwanda Aux Site Archéolgiques," in *La Cartographie Au Service de la Recherche e de l'Aménagement Du Territoire* (Glux-en-Glenne, France: Centre Archéologique Européen, 2009 (forthcoming, accepted for publication)).

[13] Scott Madry, "*Hic Sunt Dracones* (Here Be Dragons): The Integration of Historical Cartographic Data Into Geographic Information Systems," in *Between Dirt and Discussion: Methods, Materials, and Interpretation in Historical Archaeology* (New York: Springer, 2006), 33-60.

[14] Carole Crumley and William Marquardt, *Regional Dynamics: Burgundian Landscapes in Historical Perspective* (San Diego: Academic Press, 1987).

[15] Stephanie Renfrow, "Burgundy Through Space and Time," in *Sensing Our Planet: NASA Earth Science Research Features 2007*, NASA earth systems science data and services publication (Washington, D.C.: NASA, 2007).

[16] Amanda B. Tickner, "Consumption and Production at the Hill Fort Site of Mont Dardon, France: An Archeobotanical Study," Ph. D. Diss., Anthropology, University of North Carolina at Chapel HIll, 2009.

[17] Sara Bon, "Common Wares: Approaches to a Gallo-Roman Ceramic Assemblage," Ph. D. Diss., Anthropology, University of North Carolina at Chapel Hill, 1999.

[18] Elizabeth A Jones, "Surviving the Little Ice Age: Family Strategies in the Decade of the Great Famine of 1693-1694 as Reconstructed Through Parish Registers and Family Reconstitution," Ph. D. Diss., Anthropology, University of North Carolina at Chapel Hill, 2006.

[19] Elizabeth A. Jones and Carole L. Crumley, "Mont Dardon," in *Medieval Archaeology*, ed. Pam J. Crabtree (New York and London: Garland Pub., Inc., 2001), 225-26.

[20] Eric C. Straffin, "Fluvial Response to Climate Change and Human Activities, Burgundy, France," Ph. D. Diss., Geology, University of Nebraska-Lincoln, 2000.

[21] Linda R. Danner, "Sociétés Savantes and the (Re)Production of Class and Regional Identity in Burgundy, France," Ph. D. Diss., Anthropology, University of North Carolina at Chapel Hill, 2005.

[22] Elizabeth Ann Van Deventer, "Redefining the Farm, Redefining the Self: Enduring Struggles in the

The fundamental perspective has been to undertake a comprehensive and multi-faceted analysis of the changing interrelationships between people, their cultures and their environment over time in a single geographic region using multiple, integrated academic approaches.

Remote Sensing and GIS work have been conducted within this larger project since 1978, with extensive aerial photography, satellite remote sensing, and GIS work conducted.[23,24,25,26,27,28] A comprehensive GIS database containing over 150 layers has been created since 1986 and is a repository for project environmental and cultural data. One aspect of our research has been a compilation of existing historical cartographic maps of the region to extend our spatial understanding of the region back in time. Over decades we have collected a total of ten historical maps of various scales ranging from 1631 to 2002.

**Table 1. Historical maps of the study area—Project Holdings**

1. 1631 Willem J. Blaeu B&W original
2. 1659 Sanson B&W original
3. 1759 Cassini IGN B&W IGN reproduction
4. 1835/9 Communal cadastral maps photocopies of originals
5. 1847 Etat Major B&W IGN reproduction
6. 1895 Gueugnon Canton topographic color original
7. 1945 B&W Aerial photographs
8. 1964 Communal cadastral map photocopies of originals
9. 1983 1:25,000 color IGN topographic map original
10. 2002 1:25000 color IGN topographic map original

The two earliest maps (Blau 1631 and Sanson 1659), while fascinating and enjoyable as artistic and historical documents, do not have sufficient spatial reference or detail to make them useful in any quantitative analysis. It is with the development of the Cassini maps in the mid 18th century, that we have the first maps based on modern concepts of triangulation and field survey. These yield a wealth of detail with sufficient spatial accuracy to relate to modern maps and features on the ground. This work focuses on the eight later maps listed above, and the 1945 aerial photographs in our collection.

## Previous Historical Map Scanning and digitization

In 1995, when Madry was at Rutgers University, he and some of his graduate students made the first attempt to scan and extract features from the IGN reproductions of the Cassini maps of the region that had become available. The detailed map key was translated and conventional raster methods were used to extract five individual thematic spatial data layers, representing landcover, hydrology, roads, mills, and buildings. Clear

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Historical Transformation of Agriculture in Burgundy, France," Ph. D. Diss., Anthropology, University of North Carolina at Chapel Hill, 2001.

[23] Scott Madry, "Remote Sensing in Archaeology," Reprinted in French *Echos du Passé*, Bulletin du Les amis du Dardon, Gueugnon, France 1985, *Archaeology*, no. May-June (1983): 18-19.

[24] Scott Madry, "A Multiscalar Approach to Remote Sensing in a Temperate Regional Archaeological Survey," in *Regional Dynamics: Burgundian Landscapes in Historical Perspective*, ed. Carole Crumley and William Marquardt (San Diego: Academic Press, 1987), 173-235.

[25] Scott Madry and Carole Crumley, "An Application of Remote Sensing and GIS in a Regional Archaeological Survey," in *Interpreting Space: GIS and Archaeology*, ed. K. Allen, S. Green and E. Zubrow (London: Taylor and Francis, 1990), 364-380.

[26] Scott Madry and Lynn Rakos, "Line-of-Sight and Cost Surface Analysis for Regional Research in the Arroux River Valley," in *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, ed. H. D. G. Maschner, Southern Illinois University Center for Archaeological Investigations, Occasional Paper 23 (1996), 104-26.

[27] Scott Madry, "Des Gorilles Du Rwanda Aux Site Archéolgiques," in *La Cartographie Au Service de la Recherche e de l'Aménagement Du Territoire* (Glux-en-Glenne, France: Centre Archéologique Européen, 2009 (forthcoming, accepted for publication)).

[28] Stephanie Renfrow, "Burgundy Through Space and Time," in *Sensing Our Planet: NASA Earth Science Research Features 2007*, NASA earth systems science data and services publication (Washington, D.C.: NASA, 2007).

maylar overlays were created for each of the five categories and individual features were extracted and categorized using the Cassini map key which identified each feature on the maps. Each of these mylars was then manually digitized using a digitizing table and puck (see fig. 2).

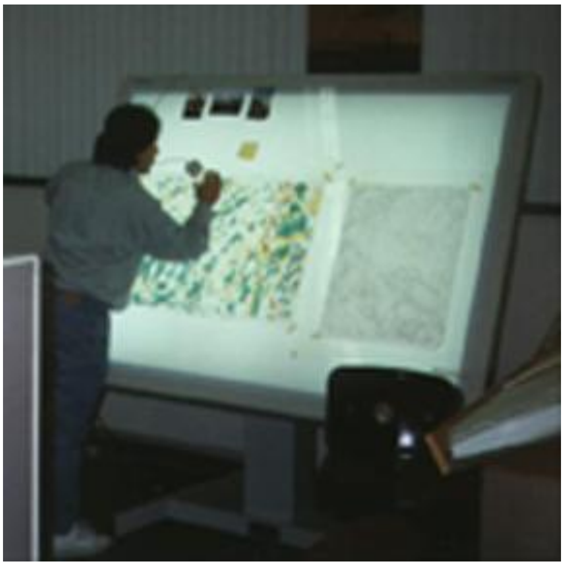

**Figure 2.**
**Manual digitizing of landcover from 1759 Cassini map.**

The maps were then scanned on a 4,000 x 4,000 pixel Eikonix digital scanner and georeferenced using GRASS GIS to match the regional landscape using towns and other features that were identifiable on both maps and had not changed location. These included old bridges, structures and other features. These Cassini thematic map layers were then integrated into the project GIS database. This project was successful and the individual component features of the map were extracted and analyzed. Total counts of mills, individual categories of structures (farms, churches, etc.) were available for review and the overall vegetation coverage of the region was created. Individual features, such as the tracts of ancient Roman roads, were located in the field and surveyed. Figure 3 shows one result of this work, with the georeferenced raster GIS Cassini map overlaid with vector historic and modern roads and streams, and different icons for each different type of structure category.

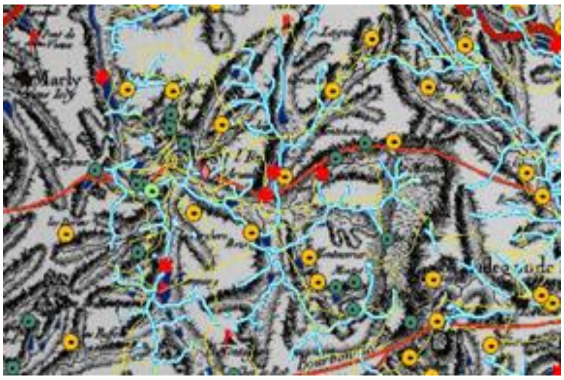

**Figure 3.**
**Digitized 1759 Cassini map with vector streams, roads, and structures**

While ultimately useful in our larger project activities, and a valuable learning experience in itself, the primary problem with this work was that, while the data and layers were internally consistent, the overall level of georeferencing precision was such that there was not an accurate correspondence at a local level. Many individual features were more than 150 meters off their actual location on the modern maps. There was also significant variation in the spatial accuracy in different areas of the map, depending on the location of control points used in the georeferencing process. This reduced the utility of the analysis of the data. The scale of the Cassini maps, level of spatial imprecision, and changes over the two hundred years between when the maps were created (1757 and 1988) made the registration insufficient for any localized comparison or detailed spatial analysis.

## 5 Manual Historical Cartographic Data Extraction Method

A state-wide archaeological predictive model was conducted in North Carolina, USA for the NC Department of Transportation (NCDOT) from 2002 to 2005.[29] The primary focus of this project

[29] Scott Madry, et al., "Development of a State-Wide Archaeological Predictive Model for the North Carolina Department of Transportation and Computerized Archaeological Database for the North Carolina Office of State Archaeology," in *GIS and Archaeological Site Location Modeling*, ed. Mark W. Mehrer and Konnie L.

was to provide NCDOT with an archaeological predictive model, decision support system, and ArcGIS internet data server to assist in the planning and evaluation of new highway alignments.[30,31] In the North Carolina predictive modeling project, over 440 historical maps were scanned and digitized covering the entire state. These maps ranged in scale from local county maps to state-wide, and ranged in dates from the early 18th century to modern maps. Initially, we attempted general georeferencing of entire maps using ArcGIS to modern USGS 1:24,000 topographic maps but these did not permit sufficiently accurate specific locations for the intended purpose or scale of use, similar to the results from the Cassini maps work described above. We needed to be able to accurately locate the modern position of historical features, including individual structures, within the zone of highway alignments, ranging from 100 to 200 meters across. Features to be extracted included agricultural, religious, commercial, residential, transportation, industrial, and manufacturing categories of data.

A new manual data extraction method was devised to improve the spatial precision of the historical features extracted from these various maps. This consisted of the following processes: first, the historical maps were color scanned on a high resolution scanner at 250 dpi as .tiff files. These files had an initial quality control evaluation to ensure the maps were properly scanned. Each map was then color printed at a scale of 1:24,000 on a commercial E-size color printer.This often required very large printing jobs and individual maps were segmented into multiple E-size printer runs. One single map could measure 3 by over 4 meters. A manual review of the map was conducted to ensure all features were properly captured. Then a mylar transparency was created of each modern 1:24,000 topo map of the area, which served as the transfer medium.

**Figure 4.**
**Manually transferring features from enlarged color map onto mylar**

A manual rubber-sheeting process was conducted where a trained GIS analyst or archaeologist familiar with the area would “line up’ or orient the mylar transparency over a small section of the historical map (see fig. 4) and visually align features that were on both maps. The analyst then manually drew the individual features from a small area onto the mylar, using a pre-defined set of icons and colors.

As soon as the transfer of features in one small area was completed, the mylar would be reoriented over an adjacent area and the process was repeated. This process was conducted on the most recent maps first, and working back in time. Once a single USGS map for a given map had all features extracted it was reviewed by another person for quality control. The mylar was then raster scanned and manually georeferenced (to itself) in the GIS, providing a high degree of spatial registration. Each individual feature was then on-screen digitized in ArcGIS and all features were entered in the Microsoft Access database. A final quality

Wescott (Boca Raton, Florida: Taylor and Francis Books, 2005), 317-334.

30 Scott Madry, et al., "North Carolina Archaeological Predictive Modeling Project: Results of Task 1: Cabarrus, Chathamn, Forsyth, Granville, Guilford, Randolph, and Wake Counties," Prepared for the NCDOT and Federal Highway Administration by Environmental Services, Inc. Report on file at ESI and NCDOT., *ESI Report of Investigation* T.I.P. number E-4602, no. 416 (September 2007).

31 Scott Madry, et al., "North Carolina Archaeological Predictive Modeling Project: Results of Task 2: Cabarrus, Chathamn, Forsyth, Granville, Guilford, Randolph, and Wake Counties," Prepared for the NCDOT and Federal Highway Administration by Environmental Services, Inc. Report on file at ESI and NCDOT., *ESI Report of Investigation* T.I.P. number E-4602, no. 416 (September 2007).

control review was conducted, always by an anlyst who did not conduct that step in the process. Each analyst was responsible for a complete step of the process and had their work reviewed by another. Notes were taken and recorded for each step.

A total of seven regional soil maps, dating from 1880-1917 were completed first, as they provided a high degree of spatial accuracy and retained many modern features without the majority of modern development. These were followed by various 19th century local and state-wide maps for areas of interest.

This method was a significant improvement over previous georeferencing methods in terms of the spatial precision of individual features over large areas. We were able to create time series of individual locations showing the progression of roads, structures, and other features (in one area of NCDOT interest) from 1833, 1878, 1914, and modern maps. These data are now available to planners and archaeologists for a variety of uses.

But the method was also slow and costly. It used large amounts of expensive E-size color paper and ink, required the printing of many maps at large sizes, and the production of multiple mylar transparencies by a commercial firm. The manual process was cumbersome and required a large working area and the large number of individual steps were difficult to maintain appropriate quality control proceedures. While it provided excellent final results, the time and cost make it unsuitable for many applications. That being said, the method provided a major improvement in spatial precision for historical feature extraction.

## 6 Digital Historical Cartographic Data Extraction Method

Based on the poor spatial results achieved by our previous French digitizing efforts and our interest in pursuing a historical ecology research activity focusing on land use and resources in the historical period, it was decided in 2006 to re-digitize not only our Cassini maps, but to conduct a systematic extraction of historical features from all relevant historical maps of our area held by our project. The initial project area was limited to the commune of Uxeau, in order to test the approach and results and because we had access to comprehensive cadastral data.

Initially, we intended to replicate the NCDOT manual process, but given the size of the area to be mapped, the number of maps and number of individual features to be extracted, it was determined that this would have been both cost and time prohibitive.

A discussion between the three authors was held in 2006, and we considered alternatives that would provide us with comparable spatial precision without the multiple steps, cost and manual approach of the NCDOT method. Several ideas were considered, and author Tickner suggested that we replicate the manual method step-for-step digitally using Adobe Photoshop. We discussed the possibility and decided to do an evaluation to determine if the method would work and determined that it would be possible, would provide acceptable spatial precision, and would be much easier. There would be several benefits to this approach, Photoshop is reasonably priced and widely available software that can be more easily learned than many dedicated commercial remote sensing or GIS packages. It also provides for a process that can be conducted entirely using Photoshop for the initial data transfer on a standard laptop computer, and is much faster than the manual method. This work was done using Adobe Photoshop version 9.0.2, on a standard HP Pavillion DV-6000 laptop running Windows XP.

### Process

The first step is to create a high resolution color scan of the modern base map and paste the image into Photoshop (see fig. 5). In our case this was a 1:25,000 topographic map from the French Institut Géographique National (http://ign.fr), the standard topographic maps covering all of France. You will need to use a dpi that has high enough resolution to see detail when you zoom in, but not so high as to slow down the operation of the Photoshop program. We worked with maps at 300 dpi but experience with the NCDOT project shows that 250 dpi is sufficient. The condition of the map is important, and folds, creases, and other problems can cause spatial errors in the final products.

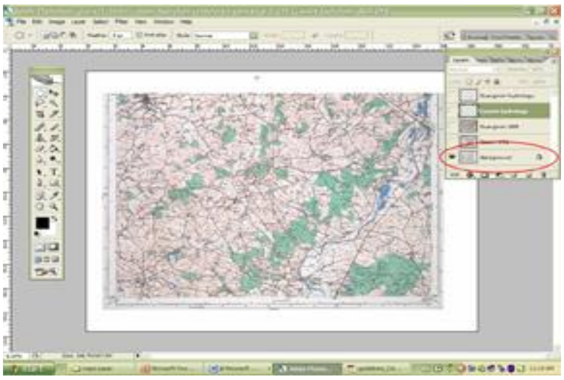

**Figure 5.**
**Modern topopgraphic map as base map**

The second step is to paste an image of the high resolution scan of the historical map from which you want to transfer data on top of the base map. This will create a new, separate layer in Photoshop (see fig. 6). These examples are from the 1895 Gueugnon Canton topographic map.

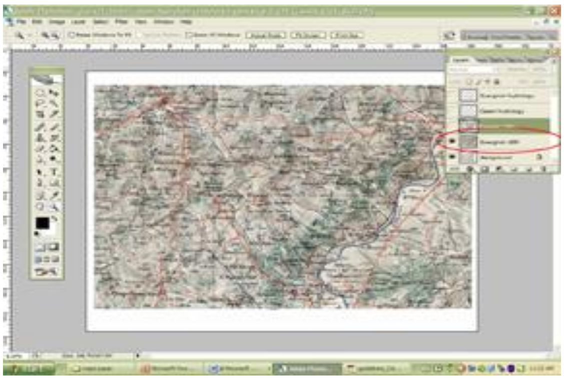

**Figure 6.**
**1895 map pasted on top of modern base map**

The third step is to adjust the size of the historical map to the base map. You do this by working with the historical map layer and reducing the opacity (See fig. 7) so that you can see through the map to the base map. Then using the ***move*** tool, align the historical map so that it lines up (as well as possible) with major features that would not have moved in location over time such as towns (See fig. 7). You will need to have the map aligned with a major feature in all four corners of the map. You will probably have to adjust the size of the historical map to get it to align. In the ***"Image Size"*** option of the drop-down ***"Image"*** menu, play with increasing or reducing the size percentage of the historical map until it aligns correctly (Be sure you have ***"Constrain Proportions"*** selected before you change the size).

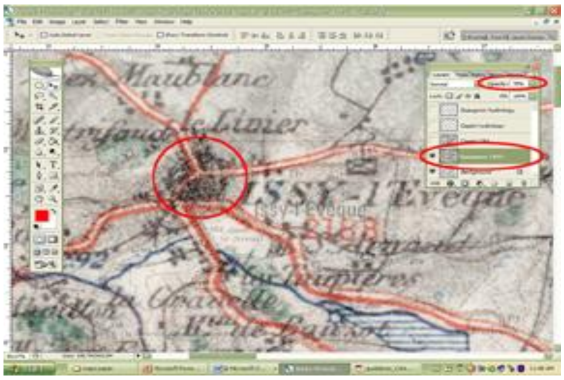

**Figure 7.**
**Transparent 1895 map lined up with modern base map**

**NOTE**: Always verify that you have the historical map seleted before you start moving the map or changing its size (see fig. 7) —you *never* move or change the size of the modern base map.

The next step is to create new layers for each type of data you want to transfer to the base map, e.g. hydrology, mills, woods, roads, etc. The first thing to do with a new data layer (hydrology in these examples), is to draw tic marks aligning it with the corners of the modern base map (see fig. 8). (Be careful to draw on the data layer on not on the base map layer)

**NOTE**: You will never move the data layer. The modern base map and the data layers *never* move. Only the historical map layers are moved in order to align the features on the data layers.

**Figure 8.**
**Tick marks created on new data layer to line up with corners of base map**

When you have finished transferring features to the data layer, it may be saved as a image by itself, and the corner marks (see fig. 9) will allow this image to be aligned later with the modern map. Figure 9 is an example of a hydrology layer created from the 1895 historical map.

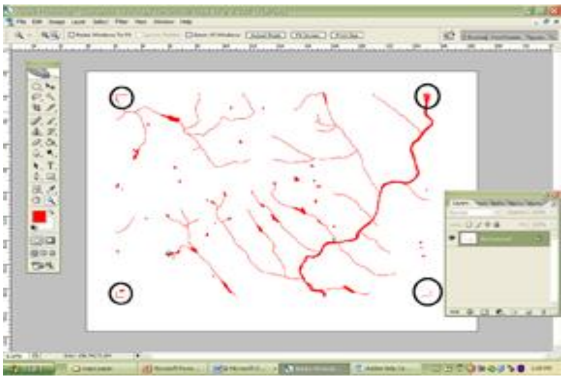

**Figure 9.**
**Hydrology layer from 1895 map with corner tick marks aligning with modern base map circled**

To start transferring data, begin by making the historical map opaque, and then zoom in on a small area and the particular features you wish to extract. Use the ***move*** tool to move the historical map and align it locally by matching up fairly stable features such as road intersections or old bridges or other structures. Be aware that features such as roads, rivers, etc. do move over time and careful consideration should be given to the choice of the features to use. The historical maps will not line up perfectly, so align it as best you can in the immediate locale of the feature you want to record on the data layer. Topographic contour lines will aid in the placement of features such as ponds. Keep in mind that there will be some outright spatial, categorical, and other errors on the historical maps. Knowledge of how the maps were created, the area's history and the local landscape is essential for minimizing these errors.

Some features will appear on both the historical and modern maps (see pond A on fig. 10), while other features (see pond B on fig. 10) appear only on the historical maps. Thus, when working with a series of historical maps, it is easiest to begin with the most recent map and work backwards in time since the more recent maps will line up with more of the modern features.


**Figure 10.**
**Ponds A on transparent 1895 map align with ponds on modern base map; Pond B on 1895 map has no modern counterpart**

Once you have aligned the historical map, switch to the data layer and draw in the features using the ***brush tool***. Fill in polygon shapes like lakes and ponds with the ***paint bucket tool*** (see fig. 11). You will probably have to switch back to the historical map layer and realign the map for each feature. When tracing a stream or river, you will have to keep realigning the historical map as you go. The area covered for each local alignment will vary by map and locale.

**Figure 11.**
**Hydrological features from transparent, aligned 1895 map drawn on separate data layer**

When you turn off the historical map layer and make the data (e.g. hydrology) layer opaque, you can then clearly see how the historical features compare with the modern map (see fig. 12).

**Figure 12.**
**Features of 1895 hydrology data layer made transparent to compare with modern base map**

Once the new data layer is complete it can be saved as a separate file, and converted to lines, points and polygons within ArcGIS for incorporation into a GIS database.

Make a new data layer for each of the other feature types from the map (e.g. wooded areas, roads, structures, etc.). You can then repeat the entire process to add another historical map to the file (see fig. 13). Always save the file in a format that will preserve the separate layers intact such as TIFF. You can also make copies of the file and save individual layers as JPEGs.

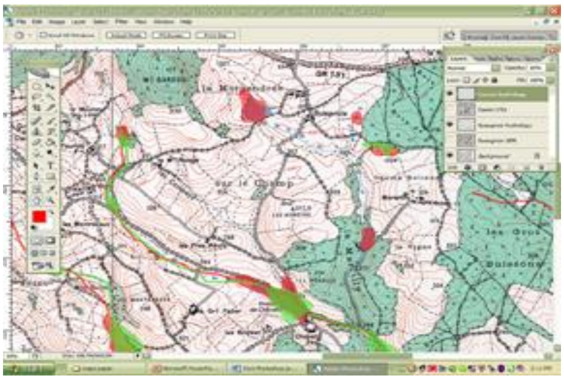

**Figure 13.**
**Hydrology from 1895 Gueugnon map in red; Hydrology from 1759 Cassini map in green**

## Quality Control

A single individual should complete a data layer and the placement of features should always be verified at the completion of each layer by someone else. Careful notes should be taken during the process to describe in detail how the work was done, and to identify any specific problems, areas of uncertainty, or other questions. The authors held weekly meetings where the location of each feature was discussed by the team, and decisions were made on how to proceed when faced with problems. The verification process included comparing the location of all features from each of the historical maps, with modern maps, other historical maps, 1945 aerial photos and Google Earth (see fig. 14 and 15).

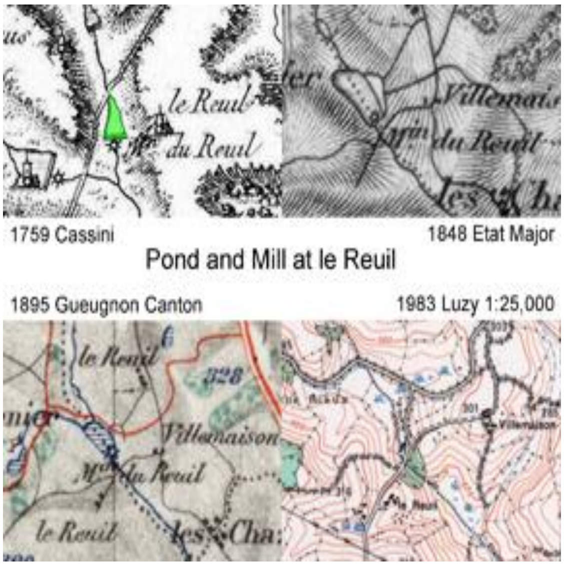


**Figure 14.**
**Location of pond on 1759 map compared with 1848, 1895 and 1983 maps**

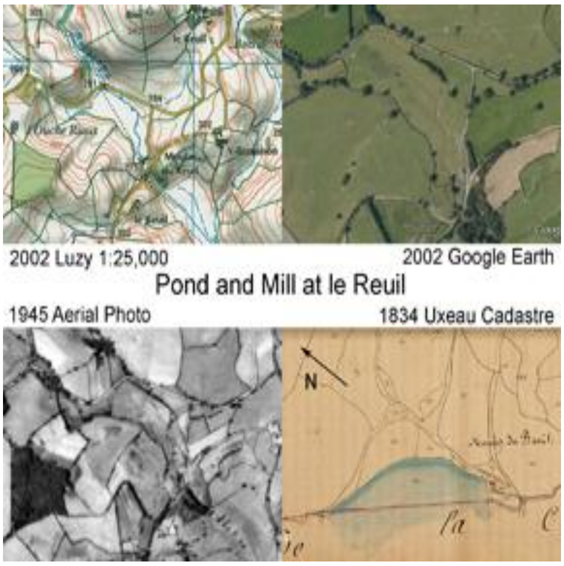


**Figure 15.**
**Pond location from 1759 map compared with 1834 cadastral map, 1945 aerial photo, 2002 topographic map and 2002 Google Earth**

It took approximately 20 hours to do the step by step transfer of one hydrology layer from one of the historical maps.

# 7 GIS Integration

Once all the individual files were created using Photoshop, the process to enter the data into our ArcGIS 9.2 environment was begun. The first step was to georeference the scanned raster 1988 topographic map to the Lambert 2 coordinate system of our ArcGIS 9.2 database. This served as the base map in ArcGIS the same way as in Photoshop. We then projected the georeferenced file to the proper projection and datum using the appropriate Arc tools. Each of the created raster files from Photoshop were then georeferenced to this same topo map using identifiable points on both maps, including, but not limited to, the corner tic marks. A high level of spatial precision was possible. We then created an ArcGIS geodatabase for the vectorization, and within it we created all the needed layers including streams (polylines), mills (points), ponds (polygons), structures (points) and vegetation classes (polygons). The projection for the database was chosen, and then each individual georeferenced raster file was manually digitized on-screen using the ArcGIS digitize tools at a scale of 1:1,000. This high zoom level was chosen for the scale of analysis that would be conducted as well as a smooth visual appearance at all levels of magnification. Next, attributes were manually added to each feature according to the categories defined beforehand. All files went through quality control upon completion of each stage of work.

The final results are that we have a georeferenced raster base map and individual vector files for each of the six historical maps that are fully integrated into our extensive existing project GIS database. These products show an excellent level of spatial precision in relationship to the basemap and each other, and are able to support the local-scale research questions for which we created the data layers.

Figure 16 shows the 1759 1:86,400 Cassini raster map in ArcGIS with the various vector hydrology data overlaid.

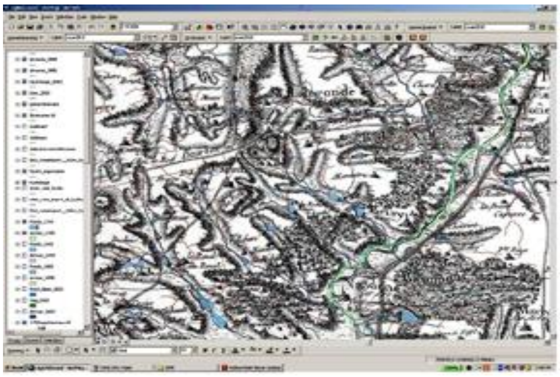

**Figure 16.**
**1759 hydrology data in GIS database**

Figure 17 shows the 1848 Etat Major 1:80,000 raster map in ArcGIS with the various vector data overlaid.

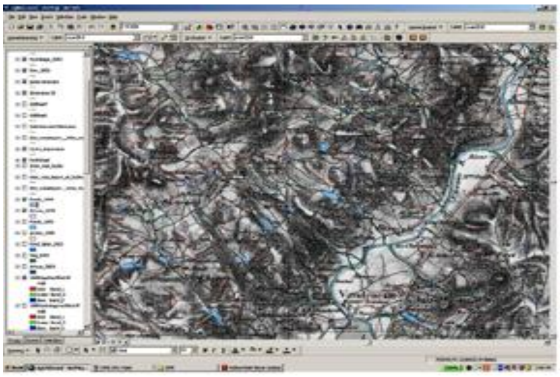

**Figure 17**
**1848 hydrology data in GIS database**

## 8 Ground Verification

The final step in the verification process was a field survey to verify the location of features on the ground. Our survey of the hydrological features (streams, ponds, dams and mill sites) was started in the Summer of 2008 (one week) and will be completed in the summer of 2009 (two weeks).

The field survey process entailed using printouts of the placement of historical features on the modern 1:25,000 topographic map and the coordinates from the GIS database to drive to the approximate area and then surveying the site on foot. The exact course of streams varies over time, so we focused on the location of ponds and dams. Hard copy color maps were produced and placed in field notebooks along with field verification forms created for this purpose.

We photographed features using a Canon Powershot digital camera (see fig. 18) and also took short panoramic movies of the surrounding areas to provide context for the site location. We took GPS readings, including elevation and direction of photo, at each photo location using a Garmin Etrex Vista. Each feature (pond, dam, mill building, etc.) was numbered and recorded on a pre-prepared site form with a brief description of the site and location (including a rough sketch if useful). Other data recorded on the field forms included date, weather conditions, field personnel, place name, ground cover, cadastral section and parcel numbers, property owner, photos (photo number, compass direction and brief description), and corresponding GPS coordinates. A notes section was provided on the form to record questions about the site and also any contextual historical data we collected from the property owners.


**Figure 18.**
**Historic pond area from 1759 map**

If corrections to our placement of historical features on the modern map were necessary, we recorded that in the notes section of the field form and drew a rough sketch of the correction on our printouts of the historical features on the topographic map. The GPS points allowed accurate corrections to be made in the GIS data base at the conclusion of the field season. The GPS points were then downloaded into Google Earth for visual inspection of each location.

## 9 Discussion and Limitations

The method described here represents a major improvement over the previous manual techniques in terms of time and effort required, cost, and complexity; while maintaining a high level of spatial precision comparable to the manual method.

The question of further automation has been considered, but, upon reflection, we feel that while additional automation of the process is possible, there is significant benefit in having a trained researcher directly involved in making decisions on the nature of the extraction to be done. While some aspects of this process could be further automated, we feel that there was great utility in our detailed visual analysis and looking at each feature in each of the maps over time. Hidden features were uncovered, patterns were perceived, and errors in the maps were identified by this detailed visual inspection. This process helped us the better understand both the changing environment and also gave us interesting insights into the various cartographic techniques and perspectives of the various map makers. We would have lost this insight if a more automated method were used.

When working with maps of multiple dates, it is best to work from the most recent back in time. We found that the data derived was sufficiently precise spatially that we could navigate on the ground using hand-held GPS to specific features. Having a detailed knowledge of the landscape and history of the region is vital to successfully extracting the most information out of each map. The old GIS saying of "garbage in, garbage out" certainly applies to this type of work, and attention to detail, note taking, and quality control are vital components of getting the best final results possible. It is also true that map scale, the intention and perspective of the cartographers, and original purpose and intended uses of the maps are all important aspects that should be thoroughly understood before any analysis is conducted and conclusions drawn. As our maps receeded back in time it was clear that the spatial precision and detail were fading away, and it would be unwise to make the same assumptions or analysis with our older maps as with the more recent ones. Even with these caveats, we have found that the work conducted was very valuable for our field activities, and that our historical cartographic data was easily verified with field observations.

The use of *Adobe Illustrator* for this work has been suggested, as this would do away with the raster to vector step in the process used here. The procedure would essentially be the same in *Adobe Illustrator*, though some of the commands will differ. *Adobe Illustrator* offers the advantage of being able to save layers as vector graphics automatically, however, its great disadvantage is that it is not as widely available or as inexpensive as *Adobe Photoshop*. Selection options/tools seem easier to use in *Adobe Photoshop*, but the capacity to manipulate and edit lines and shapes is far better in *Adobe Illustrator*. All things considered, one is not necessarily better than the other, and both will perform the tasks necessary.

This method, although a significant improvement over the manual method in time, cost, and complexity, still requires a major effort. We must have a good knowledge of the maps and their means of creation and purpose. In the end, we simply cannot fully understand the error budget of the earlier maps. It is vital that researchers carefully match their research questions with the quality of their historical cartographical data, as with all GIS data, only more so. But even with these reservations, we feel that the procedure presented here can produce data with a spatial precision appropriate for many applications that would not be possible with simple 'corner tic mark' georeferencing.

## 10 Preliminary Data Analysis

This paper focuses on the methodology of extraction of features from historical maps into the GIS context. But the goal of this work is to further our understanding of the changing patterns of land use and settlement in our study region. We have only begun our analysis of the data, but several interesting patterns have been noted.

The total number of ponds and mills has decreased over time. This is to be expected with the advent of modern transportation and the fact that local grains are no longer ground into flour locally. Several large mills and millponds are still extant in the region, but none are working mills. Many dams were purposefully breached but a few in the area were taken out by natural catastrophe, with serious loss of property and loss of life downstream. The ponds in the area served multiple functions. Many were built for mills, but not all; and several were used for raising fish that would be harvested and sold all at once every few years by draining the pond. Other uses include watering livestock (the raising of Charollais cattle is the predominant economic activity in the area) and water storage for periodic droughts. We found that many new ponds have been constructed in recent years in the same location as historical ponds. There was a devastating drought in the region in 2003 that killed much of the livestock and virtually all crops in the area. This event gave a boost to the creation of many new, smaller ponds in the region, some in the same location as older ponds, some in new places. We also found that several historical ponds that have been drained now are forest, and that this reversion to forest is a common aspect of these older ponds.

## 11 Conclusions and Future Directions

This work presents an improved method for the extraction of detailed features from historical cartographic maps with a high spatial precision. A total of six historical maps covering a range of 243 years were scanned and cultural and environmental features extracted into the GIS environment for analysis regarding patterns of continuity and change in the dynamic relationship between people and their environment. While the data extraction process is still complex and time consuming, the new method presented using Adobe Photoshop is a significant improvement over the manual method previously developed. It is more streamlined, less costly, and still maintains a very high level of spatial precision in the features extracted. The method is easily replicated and should be useable broadly by other researchers.

Our preliminary analysis of these data show a remarkably consistent pattern of settlement and land use in the region over the past 240 years. There are fewer ponds and mills, but many of ponds have been maintained, although their purpose changes over time. Woods have great continuity but there is now more variation (e.g. plantations of different tree types, woods regularly harvested or coppiced, and older growth areas) in this intensely utilized landscape. Our work will provide improved and detailed knowledge about landscape utilization in the region over this timeframe.

Additional GIS analysis is in progress and field verification will continue. In addition to the hydrology, woods, other landcover categories and roads, we will be digitizing individual structures and property ownership to more closely analyze changing property ownership and demographic patterns in the area.

We are currently georeferencing all of the 1945 aerial photos (188 of them) and extracting the same categories of features as the historical maps from these aerial images.

Our analysis of forest cover has begun, and we will create a dynamic map of the loss and regrowth of forest for the study area.

Ongoing field work in the summer of 2009 will include collection of oral history accounts of landscape features and ethnographic interviews from farmers about their current and past strategies relating to land use.

Our cadastral map work will also continue, and we will next digitize, using the same methods presented here, the 1834 and 1966 cadastral land use and and parcel data for the commune of Uxeau. This will allow more detailed temporal and spatial analysis of changes in land use (e.g. vineyards, pastures, gardens, orchards, etc.), year by year, back to 1834. When the individual property owners from the cadastral records are linked to farm families and their social networks through historical demographic data, we can begin to look at the strategies behind the changes in land use.

Our analysis of the ponds and mills continues. We will conduct a spatial analysis of the mills and millponds over time, including analysis of the distance needed to travel to a millsite and changing patterns of availability of mills. We will look at changes in types of water use over time comparing the different map data. This will be analyzed in relationship to changes in land use within the larger political, socio-economic, and market contexts.

## Acknowledgements

The authors wish to thank the Institut Géographique National, the Archives Départementales de Saône-et-Loire, and the Marie of the Commune of Uxeau, France for their kind permission to use their maps. We also acknowledge the contributions of project collaborators Dr. Carole Crumley, who provided the 1895 map, and Dr. Dennis McDaniel. Both supported this effort directly. Our grateful appreciation goes out to our friends and colleagues in Burgundy.

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